NON-DESTRUCTIVE METHODS IN CONCRETE BLAST RESISTANCE ASSESSMENT

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Abstract: The paper deals with the assessment of material used for the construction of protective structures and elements of military and civilian infrastructure. Since the main reason of protective structures is to protect personnel, equipment and equipment from attack by hostiles, it is necessary to conduct tests of material ballistic resistance and resistance against contact or distant explosion when choosing suitable materials for building protective structures.

In order to achieve the aim of this work, from several basic groups of NDT methods was selected. Based on the evaluation of their advantages and technical possibilities, representatives from 4 principally and physically different groups of NDT methods were selected, i.e. visual method, ultrasonic method, hardness method and resonance method.

The practical part of the paper is focused on the design of the material evaluation by means of NDT methods. In the first stage, the setting of the measuring devices was performed. Laboratory measurement was then carried out, on the basis of which calibration relations were established to determine the basic mechanical properties of the material. The material evaluation is described fort both, newly designed elements and for material in already built structures. Laboratory and field tests were performed during the assessment of the material of the newly constructed elements. In laboratory tests, the test specimens were evaluated by NDT methods. In the field tests, the test specimen was subjected to an explosion, the effect of which was subsequently evaluated by NDT methods and compared with the results of the same method prior to loading.

Keywords: PROTECTIVE STRUCTURES, NDT, MATERIAL ASSESSMENT, ULTRASONIC TEST METHOD, HARDNESS TEST METHOD, RESONANCE TEST METHOD

1. Introduction

In practice, NDT methods have a wide range of uses. NDT methods are used mainly in medicine, construction and engineering. In the construction industry, NDT methods are mainly used for the diagnostics of concrete and reinforced concrete structures. In particular, the strength characteristics of the concrete, the position, shape and layout of the reinforcement are detected, and are used for detecting defects in concrete or reinforced concrete structures. [1]

The main advantage of NDT methods is that the measurement does not damage the element or structures. Other advantages of using NDT methods are: measurement speed, unlimited number of measurements and the possibility of measuring existing structures. However, these methods have two important disadvantages. The first disadvantage is that the methods measure the indirect values, which means that the searched quantity (compressive strength, modulus of elasticity ...) is calculated from the measured quantities (UZ speed, hardness ...). The second disadvantage is the reliability of the results, which depends on the accuracy of the measurement and the size of the errors. The biggest measurement error is caused by the person making the measurements. For this reason, it is very important that measurements are made by the same person. [2]

Based on the evaluation of their advantages and technical possibilities, representatives from 4 principally and physically different groups of NDT methods were selected, i.e. visual method, ultrasonic method, hardness method and resonance method. The principle of functioning and measurement of these NDT methods is described in [1] [3] [4] [5] [6] [7] [8] [9].

Because the protective elements and structures serve primarily to protect people, property and critical infrastructure [10], both in civilian and military use, these structures are loaded with dynamic explosion strain. For this reason, steel fibre reinforced concrete [11] [12] is used for the building of protective elements and structures. Because of the steel fibre reinforced concrete we are able to accomplish the requirements of the mechanical properties of the material, which must have sufficient compressive strength, but on the other hand the smallest static modulus of elasticity. To determine the material properties and defects in material and construction were used NDT methods.

2. Laboratory tests

Laboratory tests of the material are performed on the test samples. As test samples are used 150 mm cubes and prisms 100 x 100 x 400 mm which were produced for this work according to CSN EN 12390-2 [12].

The following NDT methods were used to perform laboratory tests: ultrasonic method, resonance method, hardness method. By these methods are determined the basic properties of the material. The measured values are used to control the material for building protective elements and structures, if the correct material has been used. It is also used to create an explicit model in ANSYS

The test bodies are marked and the NDT measurements are performed. Using the method, the velocity values of the transverse and longitudinal ultrasonic waves are measured. With a resonant device are measured the values of the resonance frequencies (longitudinal, transverse and torsional resonant frequency). The measured values are assigned to the calculation formulas of the dynamic modulus of elastic [7] [9]

A hardness method is used to determine the compressive strength of the material. For this method were used SilverShmidt ST/PC. Each sample is measured at min. 10 measurements. After measurements are performed by NDT methods, measurements are carried out by destructive methods to determine the real values of the basic mechanical properties of the material. Destructive methods are used to determine: compressive strength, static modulus of elasticity and static shear modulus.

The relationship between dynamic and static modulus of elasticity is calculated for evaluation of the ultrasonic method and resonance method.

Table 1: *Measured values of the method and the resonance method.*

	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	sample 7	sample 8	sample 9	sample 10
a [m]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
b [m]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
L [m]	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
ρ [km/m3]	2374	2439	2439	2458	2384	2430	2363	2456	2438	2419
m [kg]	9.495	9.755	9.755	9.83	9.535	9.72	9.45	9.825	9.75	9.675
f_L [kHz]	5.566	5.524	5.524	5.505	5.328	5.615	5.585	5.511	5.688	5.603
f_T [kHz]	3.265	3.247	3.198	3.229	3.052	3.198	3.241	3.168	3.284	3.21
f_f [kHz]	2.393	2.356	2.327	2.283	2.167	2.35	2.319	2.283	2.362	2.332
v_{L3} [m/s]	4896	4896	4926	4866	4854	4981	4932	4957	4994	4926
E [MPa]	39000	39200	40000	40200	36000	41200	38400	39300	43000	40800
G [MPa]	16000	16200	15900	16200	14000	15900	15800	15600	16500	15900

__Table 2:__ Resulting values of reduction coefficients.

$\chi_{r,EL}$	0.83
$\chi_{r,EF}$	0.88
$\chi_{r,G}$	0.84
$\chi_{u,E}$	0.77
$\chi_{u,G}$	0.73

In table 2 are values of reduction coefficients where:

$\chi_{r,EL}$... the reduction coefficient for calculating the static modulus of elasticity by the resonance method,

$\chi_{r,G}$... the reduction coefficient for calculating the static shear modulus by the resonance method,

$\chi_{u,E}$... the reduction coefficient for calculating the static modulus of elasticity by the ultrasonic method,

$\chi_{u,G}$... the reduction coefficient for calculating the static shear modulus by the ultrasonic method.

To evaluate the hardness method, calibration relationships are required. It is necessary to find the line equation that has the general relation $R_{be} = ax + b$. The least squares method is used to find the straight-line equation.

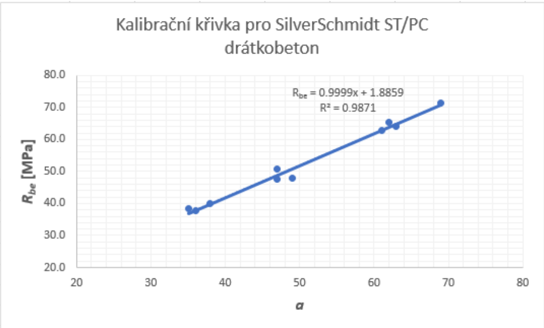

Fig. 1 *Calibration curve for Silverschmidt ST / PC*

Line Equation of a line has shape: $\mathbf{R_{be} = 0.9999x + 1.8859}$ and standard deviation **2 Mpa** (Fig. 1)

3. Field tests

Field tests of the material are performed to determine the ballistic resistance and the explosive resistance of the material. For the determination of the ballistic resistance are used test samples 500 x 500 x 40mm. To measure the explosive resistance of material are used test samples 1000 x 1000 x 50-160 mm, where the width of the test sample depends on the character of the tested material. Also are used test samples 6000 x 1500 x 300 mm (imitation of bridge construction 1:1) and frame construction (Fig. 2) made of tested material (imitation of protective structure) or existing protective structure. Test samples may have different dimensions depending on which type of critical infrastructure is being tested.

Fig. 2 *Frame construction*

Before the field tests begin, a measure point network (Fig. 3) is marked on the test material or construction.

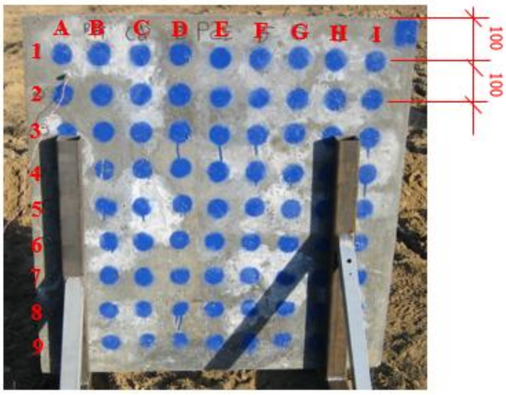

Fig. 3 *Network of measurement points*

The ultrasonic method and the hardness method are used before the explosion. In the sounding of the material are used the transmission direct method and the transmission indirect method. If the construction would not be accessible from both sides, it would be necessary to use the reflection method. Measuring with device with transmission direct method are measured all points on the test sample. It starts at point A1 on both sides and proceeds to point I9. Because cracks can occur anywhere in the material and not just directly at the points, the material must be sounded by a transmission indirect method. This means that diagonals, rows and columns are sounded. Then are indicated points on the test sample for the hardness method. These points must be spread the whole test sample or construction.

After the NDT method is measured, the weight and the position of the explosive will be selected and will be selected between contact explosion and distant explosion. The distance of the explosive from the test sample is determined by the weight of the explosive and the requirements.

First is used the visual method after the explosion. The basic measurement of this method is a human eye. This means that the person is looking for the visible cracks in the test sample or construction. The visible cracks are highlighted by a spray. Then the thickness of these cracks can be determined by 50x magnification microscope (Fig.4).

Fig. 4 *50x magnification microscope*

If an explosion cause hole in the test sample, this hole is measures by the tape measure (Fig. 5).

Fig. 5 *Measuring the hole in the test sample*

The next measurement of the test sample after the explosion is done by the ultrasonic method. Measurement by this method is the same as when measuring the test sample before the explosion. Then is used hardness method.

The evaluation of field tests consists in comparing the values measured before and after the explosion. The values measured by the ultrasonic method and the values measured by the hardness method are compared. For the evaluation of the field test was used program 3DField pro. This program is used for graphical interpretation and evaluation of results. This program converts data into contours of maps and surface areas. All aspects of 2D or 3D maps can be tailored to create a precise presentation. The test data was imported into this program. These data are imported using the coordinate system, so it is important to specify coordinates for each measurement point. Each point has an assigned measured value of ultrasonic wave velocity.

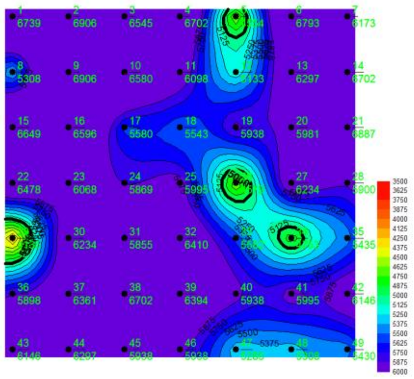

Fig. 6 *The contour layouts before the explosion*

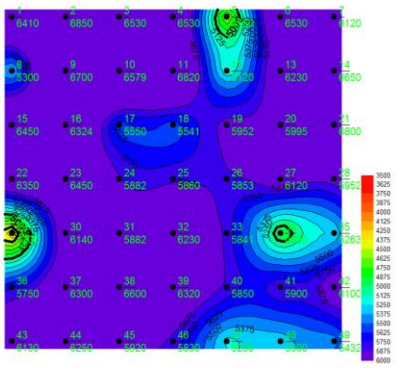

Fig. 7 *The contour layouts after the explosion*

Fig. 6 and 7 illustrate an example of field test evaluation. There are the contour layouts of the tested test sample before and after the explosion. When evaluating the effect of the explosive on the test sample, these images are compared. After comparing *Fig.6* and *7*, we can say that the test sample was made of high quality material.

4. Conclusion

For this paper were selected NDT methods based on the evaluation of their advantages and technical possibilities, representatives from 4 principally and physically different groups of NDT methods, i.e. visual method, ultrasonic method, hardness method and resonance method.

In the chapter laboratory tests were used NDT methods. For using these methods were created calibration curves and relationships to determine the mechanical properties of the material used for building protective elements and structures.

In the chapter field tests were tested explosive resistance of the test sample. NDT methods were used for searching cracks in the material from which the test samples were made. In the end of this paper were compared results before and after explosion.

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